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EFFECTS OF CERIUM OXIDE NANOPARTICLE ADDITION IN DIESEL AND DIESEL-BIODIESEL-ETHANOL BLENDS ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF A CI ENGINE

V. Arul Mozhi Selvan, R. B. Anand and M. Udayakumar
Department of Mechanical Engineering, National Institute of Technology,Tiruchirappalli, Tamil Nadu, India
E-Mail: arulmozhi@nitt.edu

ABSTRACT

An experimental investigation is carried out to establish the performance and emission characteristics of a compression ignition engine while using cerium oxide nanoparticles as additive in neat diesel and diesel-biodiesel-ethanol blends. In the first phase of the experiments, stability of neat diesel and diesel-biodiesel-ethanol fuel blends with the addition of cerium oxide nanoparticles are analyzed. After series of experiments, it is found that the blends subjected to high speed blending followed by ultrasonic bath stabilization improves the stability. The phase separation between diesel and ethanol is prevented using vegetable methyl ester (Biodiesel) prepared from the castor oil through transesterification process. In the second phase, performance characteristics are studied using the stable fuel blends in a single cylinder four stroke computerised variable compression ratio engine coupled with an eddy current dynamometer and a data acquisition system. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall results reduction in HC emissions. The tests revealed that cerium oxide nanoparticles can be used as additive in diesel and diesel-biodiesel-ethanol blend to improve complete combustion of the fuel and reduce the exhaust emissions significantly.

Keywords: diesel engine, engine emissions, cerium oxide, diesel-biodiesel-ethanol blends, nanoparticles.

INTRODUCTION

The compression ignition engines are widely used due to its reliable operation and economy. As the petroleum reserves are depleting at a faster rate due to the growth of population and the subsequent energy utilization, an urgent need for search for a renewable alternative fuel arise. Also the threat of global warming and the stringent government regulation made the engine manufacturers and the consumers to follow the emission norms to save the environment from pollution. Among the many alternative fuels, ethanol and biodiesel (vegetable methyl esters) are considered as a most desirable fuel extender and fuel additive due to its high oxygen content and renewable in nature. Among the challenges of using ethanol in diesel engines, phase separation poses a major barrier with the blending technique. The use of co-solvents acts as a bridging agent through molecular compatibility and bonding to produce a homogeneous blend. Stability studies of diesel ethanol blends with the use of various additives are reported by various researchers [1-5]. As the costs of the commercially available additives are high, the present work is focused on the use of castor oil methyl ester as additive to prepare various stable ethanol-diesel blends.

Among the various techniques available to reduce exhaust emissions, the use of fuel-borne catalyst is currently focused due to the advantage of increase in fuel efficiency while reducing harmful greenhouse gas emissions and the health-threatening chemicals such as NOx and particulate matter. The influence of cerium oxide additive on ultrafine diesel particle emissions and kinetics of oxidation was studied by Jung *et al.* [6]. They found that addition of cerium to diesel cause significant reduction in number weighted size distributions and light-off temperature and the oxidation rate was increased significantly. Escribano *et al.* [7] studied the structural and morphological characterization of a Ce-Zr mixed oxide supported Mn oxide as well as on its catalytic activity in the oxidation of particulate matter arising from Diesel engines. Mn-Ce-Zr catalyst shows high activity in the soot oxidation producing CO_2 and CO as a by-product in the range 425-725 K. Idriss studied the complexity of the ethanol reactions on the surfaces of noble metals/cerium oxide catalysts [8]. The hazard and risk assessment with the use of nanoparticle cerium oxide bases diesel fuel was studied by Barry Park *et al*. [9]. Auffan *et al*., [10] studied the potential *in vitro* cyto- and genotoxicity of nano-sized CeO_2 on human dermal fibroblasts. In the present work, the stable diesel ethanol fuel blends are prepared using castor oil methyl ester as additive and the emission reduction potential are investigated using cerium oxide nanoparticles as fuel borne additive with neat diesel and diesel-biodiesel-ethanol blends on the compression ignition engine.

EXPERIMENTAL SETUP AND PROCEDURE

The stability test is conducted to identify the phase separation phenomena of the diesel ethanol blends. Also the use of cerium oxide nanoparticle in neat diesel and diesel ethanol blend has the tendency to settle down at the fuel tank. Ethanol (99.9% purity) and cerium oxide nanoparticle with the size of 32nm are used in the tests.

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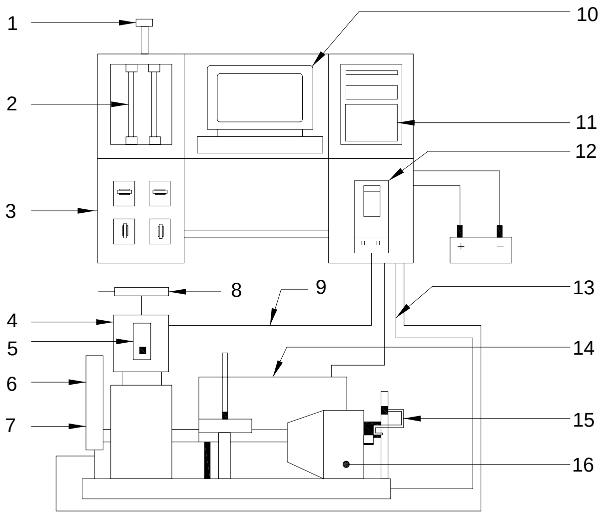
After series of experiments, it is found that the blends subjected to high speed blending followed by ultrasonic bath stabilization improves the stability. The phase separation between diesel and ethanol is prevented using vegetable methyl ester (Biodiesel) prepared from the castor oil through transesterification process. The properties of the fuel blends are shown in Table-1. All the blends are observed for phase separation at an interval of half an hour and the turbidity procedure is used to assess the stability of the resulting suspension. The detailed procedure and experiment test facility is explained by Arul Mozhi Selvan *et al*., [4-5].



1. Fuel tank inlet	2. Fuel flow sensors
3. Control Panel	4. VCR Engine
5. Pressure Sensor	6. Crank angle encoder
7. Speed sensor	8. Air flow sensor
9. Exhaust gas line	10. Computer
11. Data capture card	12. Gas Analyzer
13. Fuel line	14. Gas calorimeter
15. Load Sensor	16. Dynamometer

Figure-1. Experimental setup of computerized variable compression ratio test rig.

The performance tests for the stable Diesel-biodiesel-ethanol blends and neat diesel with cerium oxide nanoparticles as fuel-borne catalyst additive are carried out on a computerized single cylinder four stroke direct injection variable compression ratio engine. Figure-1 shows the schematic diagram of the experimental setup and the Table-2 shows the specification of the engine. The experimental setup consists of a variable compression ratio engine is coupled to an eddy current dynamometer. A computerized data acquisition system is used to collect, store and analyze the data during the engine testing. A Kistler piezoelectric pressure transducer and a crank angle encoder is used to measure the in-cylinder gas pressure and the corresponding crank angle. The load applied on the engine is measured by the load cell connected to the eddy current dynamometer. A burette with two infra red optical sensors measures the fuel flow rate, an air flow sensor measure the inlet air flow rate, K type thermocouples measure the inlet air and exhaust gas temperatures. AVL DIGAS analyzer is used to measure the exhaust gas constituents such as CO, HC, NO and the smoke is measured using the AVL smoke meter. All the experiments are conducted at the compression ratio of 19 and the results are recorded under steady state conditions.

Table-1. Properties of the fuel blends.

Properties	**Diesel**	**Ethanol**	**Castor oil**	**D70 C10 E20**
Kinematic Viscosity @ 40˚C,cSt	2	1.1314	245	2.35
Density @ 15˚C, gm/cc	0.83	0.79	0.965	0.8275
Flash Point, ˚C	50	13.5	230	11
Fire Point, ˚C	56	-	242	14
Cetane Number	46	6	48	44.6
Net calorific value, MJ/kg	42.30	25.18	39.5	39.0

Table-2. Specification of the engine.

Brake Power	3.7 kW
Speed	1500 rpm
Compression ratio	5:1 to 20:1(Variable)
Bore	80 mm
Stroke	110 mm
Ignition	Compression ignition
Cooling	Water cooled
Loading System	Eddy current dynamometer

RESULTS AND DISCUSSIONS

The following section illustrates the results obtained from the performance and emission characteristics of the CI engine. The variation of specific fuel consumption with brake mean effective pressure (bmep) is shown in Figure-2.

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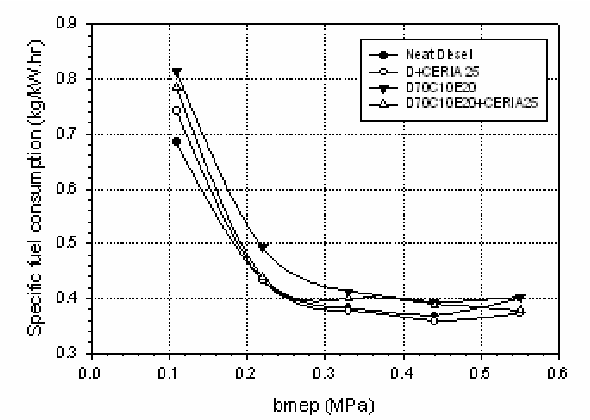

Figure-2. Variation of specific fuel consumption with brake mean effective pressure.

The specific fuel consumption is higher for the diesel ethanol blends than neat diesel at all the bmep. This is due to the lower calorific value of the diesel ethanol blend than neat diesel; more quantity of fuel is consumed to maintain the engine speed constant. The lowest sfc is observed as 0.3586kg/kW.hr for the D+CERIA25 blend whereas it is 0.3931kg.kW.hr for neat diesel at the bmep of 0.44Mpa. This phenomenon is due to the result of cerium oxide addition which promotes combustion.

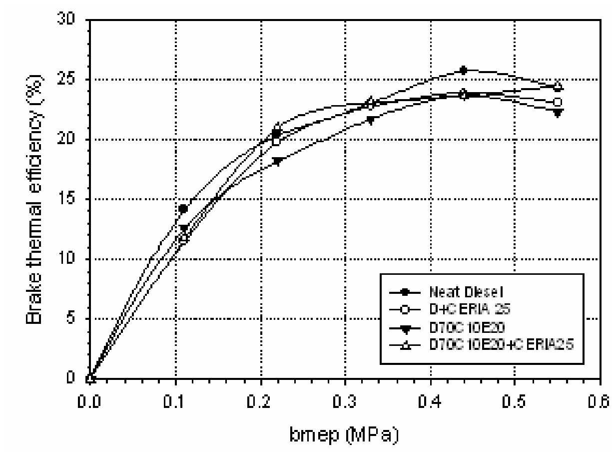

Figure-3. Variation of brake thermal efficiency with brake mean effective pressure.

The variation of brake thermal efficiency with bmep is shown in Figure-3. The brake thermal efficiency of the neat diesel is higher among all the fuel blends. The brake thermal efficiency of the diesel ethanol blends are lower due to lower calorific value of the blend. However a small improvement in brake thermal efficiency is observed with the addition of cerium oxide with diesel ethanol blends. The highest brake thermal efficiency is observed as 25.66% for neat diesel whereas it is 23.63% for the D70C10E20 blend under the same bmep of 0.44MPa.

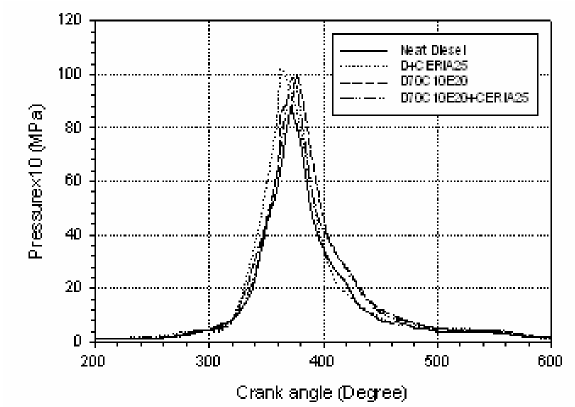

Figure-4. Variation of cylinder pressure with crank angle at the bmep of 0.44 MPa.

The variation of cylinder gas pressure with crank angle is shown in Figure-4. It is observed that the peak pressure increases with the addition of cerium oxide and ethanol in diesel. The addition of cerium oxide with neat diesel and diesel-biodiesel-ethanol blends accelerates early initiation of combustion and the ignition delay decreases. The addition of ethanol increases the ignition delay, hence more fuel is accumulated in the premixed combustion phase is the cause for faster combustion which results in higher peak pressure. The highest peak pressure is observed as 10.2MPa for the D+CERIA25 blend, whereas is 8.4MPa for neat diesel.

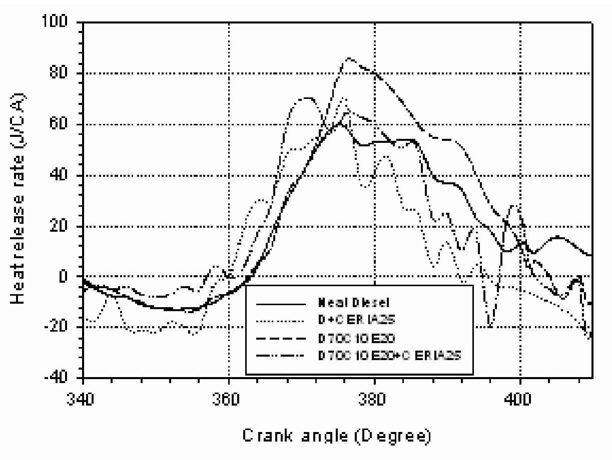

Figure-5. Variation of heat release rate with crank angle at the bmep of 0.44MPa.

The variation of heat release rate with crank angle is shown in Figure-5. The heat release rate increases with the addition of ethanol in diesel. The longer ignition delay due to the addition of ethanol is the cause for the rapid combustion in the premixed phase results in higher heat release rate. The addition of cerium oxide accelerates combustion and cause for the lower heat release rate when comparing with diesel-biodiesel-ethanol blend. The highest heat release rate is observed as 84J/CA for the

D70C10E20 blend at the bmep of 0.44MPa, whereas it is 60 J/CA for neat diesel.

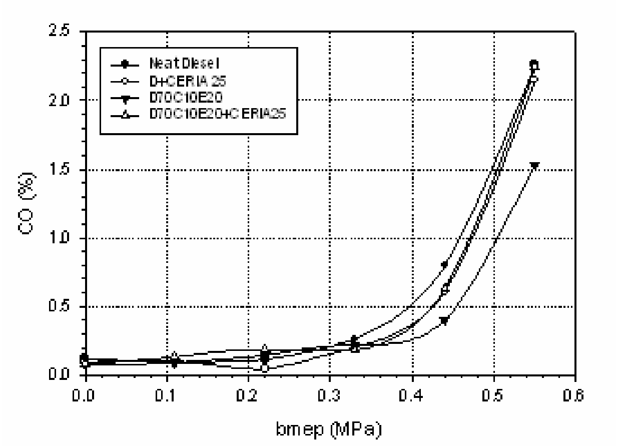

Figure-6. Variation of carbon monoxide with brake mean effective pressure.

The variation of carbon monoxide with bmep is shown in Figure-6. The carbon monoxide emission decreases with the use of diesel-biodiesel-ethanol blends than neat diesel. The CO emission is marginal up to the bmep of 0.44 MPa and then increases rapidly with higher load. The addition of cerium oxide further decreases the CO emission when comparing with neat diesel.

The variation of hydrocarbon emission with bmep is shown in Figure-7. The addition of cerium oxide decreases the HC emission when comparing with neat diesel and diesel-biodiesel-ethanol blends. The use of oxygenated additives promotes complete combustion is the cause for the hydrocarbon emission reduction. The least HC emission is observed as 97 ppm for the D+CERIA25 blend at the bmep of 0.44 MPa.

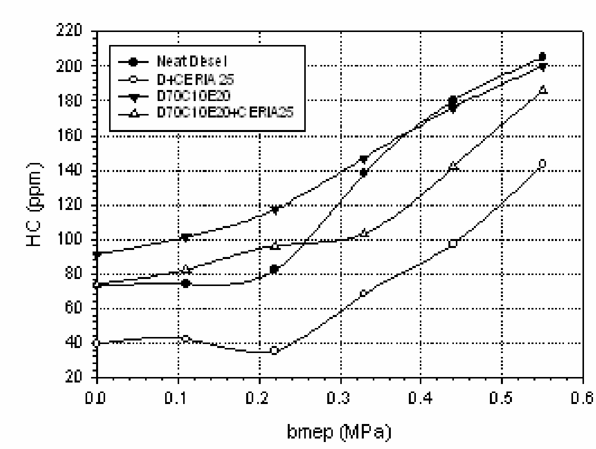

Figure-7. Variation of hydrocarbon with brake mean effective pressure.

The variation of nitrogen oxide with bmep is shown in Figure-8. The NO emission is lower for the neat diesel when comparing to all the fuel blends. The effect of oxygenated additives enhances combustion and the longer ignition delay due to the ethanol addition results in faster premixed combustion is the cause for higher combustion temperature and the subsequent higher NO emission. The least NO is observed as 250ppm for neat diesel at the bmep of 0.44 MPa.

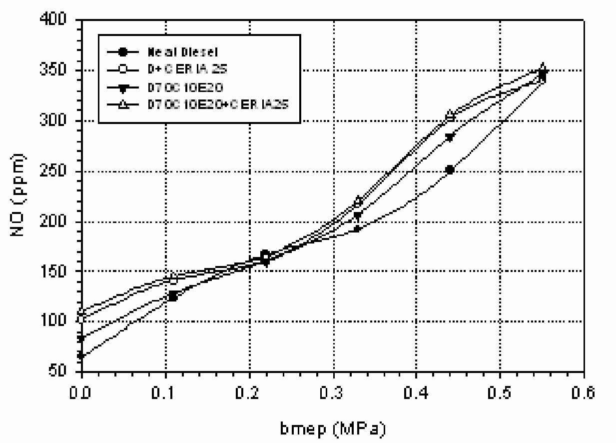

Figure-8. Variation of Nitrogen oxide with brake mean effective pressure.

The variation of smoke absorption coefficient with bmep is shown in the Figure-9. The smoke decreases with diesel ethanol blends when coparing with neat diesel. Also the addition of cerium oxide in neat diesel and diesel ethanol blends decreases the smoke further.

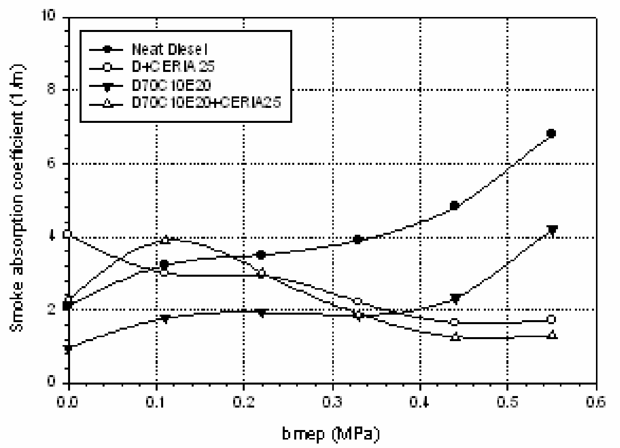

Figure-9. Variation of smoke absorption coefficient with bmep.

The use of oxygenated fuel improves better combustion is the cause for the smoke reduction. The least smoke absorption coefficient is observed as 1.273 for the D70C10E20+CERIA25 blend at the bmep of 0.44 MPa.

The variations of the relative air-fuel ratio (Lambda) with brake mean effective pressure is shown in Figure-10. It is observed that at lower loads, the relative air-fuel is higher and decreases as the load increases. This shows that the engine operates at lean mixtures and approaches towards stoichiometric region at higher loads. The addition of ethanol and cerium oxide with neat diesel helps the engine to operate leaner. However it is found that at all the loads the engine operates at lean mixtures and at overload conditions all the blends are working at same relative air fuel ratios.

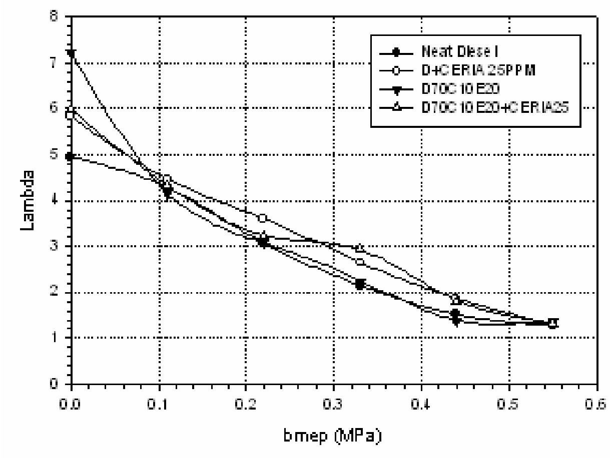

Figure-10. Variation of relative air fuel ratio with bmep.

CONCLUSIONS

The performance and emission characteristics of neat diesel and diesel-biodiesel-ethanol blends with the addition of cerium oxide nanoparticles are investigated to evaluate the emission reduction potential on the single cylinder CI engine. The conclusions of this investigation are as follows:

- The castor oil biodiesel prevents phase separation among diesel and ethanol blend and the stability of the blend with the addition of cerium oxide improves with high speed blending and ultrasonic bath stabilization technique;
- The specific fuel consumption is higher for the diesel-biodiesel-ethanol blends than neat diesel at all the brake mean effective pressures. The brake thermal efficiency of neat diesel is higher than diesel-biodiesel-ethanol blends at all the loads and a small improvement is observed with the addition of cerium oxide with diesel ethanol blends;
- The peak pressure increases with the addition of cerium oxide and ethanol in diesel. The addition of ethanol in diesel increases the ignition delay whereas the addition of cerium oxide decreases the ignition delay. The heat release rate increases with the addition of ethanol in diesel. The addition of cerium oxide accelerates earlier initiation of combustion and cause for the lower heat release rate when comparing with diesel-biodiesel-ethanol blend;
- The carbon monoxide emission decreases with the use of cerium oxide nanoparticles in diesel-biodiesel-ethanol blends and neat diesel. The addition of cerium oxide decreases the HC emission when comparing with neat diesel and diesel-biodiesel-ethanol blends. The NO emission is lower for the neat diesel than the oxygenated blends. The smoke decreases with the fuel blends with oxygenated additive. The addition of cerium oxide nanoparticles in neat diesel and diesel-biodiesel-ethanol blends decreases the smoke further; and
- The relative air-fuel ratio is higher at lower bmep and decreases as the bmep increases. Under all the loads, the addition of cerium oxide with neat diesel and the diesel-biodiesel-ethanol blend helps the engine to operate at lean mixtures than the neat diesel.

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Nomenclature

bmep	Brake mean effective pressure, MPa
sfc	Specific fuel consumption, kg/kW.hr.
CA	Crank angle, degree
CO	Carbon monoxide, %
HC	Hydrocarbon, ppm
NO	Nitrogen oxide, ppm
D70C10E20	70%Diesel +10%Biodiesel+20%Ethanol
CERIA25	Cerium oxide nanoparticles of 25ppm

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